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PRE-SERVICE TEACHERS' EXPERIENCES IN USING 3D PENS FOR PRIMARY BIOLOGY AND CHEMISTRY EDUCATION

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Abstract. *Three-dimensional (3D) pens are emerging educational tools that enable users to create tangible, freeform 3D printed models. However, their pedagogical potential in science education remains underexplored. This study examined pre-service teachers' experiences using 3D pens to create models for primary biology and chemistry education, focusing on their development of science skills, perceptions, and problems encountered. Thirty-four Bachelor of Elementary Education (BEEd) pre-service teachers from a state university campus in the Cordillera Administrative Region (CAR), Philippines, participated in a sequential explanatory mixed-method design. Results revealed that the pre-service teachers strongly agreed that using 3D pens enhanced their creativity and technological skills. They encountered problems such as the pens' need for a constant power supply, unpleasant filament odors, and difficulty in creating precise and durable models. They noted the lack of skills and mastery in using the pens, as well as the need for extended user practice. This study supports that 3D pens are accessible and innovative tools that can enhance primary biology and chemistry lessons. It further implies that teacher education programs can adopt the pens, equipping future educators with experiential competence in delivering engaging, student-centered science learning.*

Keywords: *3D pens, 3D printed models, primary biology and chemistry education, primary pre-service teachers, Philippines*

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Introduction

The relentless pursuit of technological innovation has enabled humanity to tackle complex problems and unlock new opportunities. One such innovation is the use of three-dimensional (3D) printing technology, which offers novel possibilities for transformation, sustainability, and customization across various disciplines. It has profoundly impacted education, transforming how students learn, engage with subjects, and prepare for future careers. 3D printing technology, also known as additive manufacturing (AM), builds 3D objects by forming or fabricating layers of materials (Novak & Wisdom, 2018; Shahrubudin et al., 2019; Ugaldi et al., 2025). When students engage in 3D printing activities, they are invited to take ownership of the design process. Hence, this strongly supports the integration of 3D printing technologies into science, technology, engineering, and mathematics (STEM) education, as well as the inclusion of art disciplines into science, technology, engineering, arts, and mathematics (STEAM) curriculum.

Among the different forms of 3D printing technology, the 3D pen stands out for its simplicity and hands-on engagement. The 3D pen is a portable, thick, cylindrical instrument that extrudes thermoplastic filaments of various colors, enabling users to create 3D sculptures and drawings (Kolitsky, 2014) in a manual and freehand manner (Bernard & Mendez, 2020; Kim & Lee, 2021). It utilizes a fused filament fabrication (FFF) technique, which uses a heated nozzle to eject melted filaments that construct objects layer by layer (Kim & Lee, 2021). It prints objects quickly (Chun, 2021), enabling users to create and modify diverse designs instantly (Bernard & Mendez, 2020; João et al., 2020; Takahashi & Kim, 2019).

3D pen's functionality is further complemented by its user-friendliness and affordability, making it an attractive option for educational settings and students of all ages. It is easy to operate (Cardoso et al., 2020; João et al., 2020), and it does not require software or digital file transfer to function (de Oliveira et al., 2020; Takahashi & Kim, 2019). It is more affordable (Cardoso et al., 2020; Chun, 2021; de Oliveira et al., 2020; Fidan et al., 2020) and the best substitute for a 3D printer (de Oliveira et al., 2020; Takahashi & Kim, 2019).

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3D pens can be used anywhere, eliminating the need for a complex laboratory setup (João et al., 2020). Notably, users can learn immediately after a short time of practice (Bernard & Mendez, 2020). As a result, 3D pens are gaining popularity among young students (Kim & Lee, 2021). It enables spontaneous, hands-on creation, encouraging open-ended exploration, creativity, and tactile learning, promoting student-centered learning.

Building on these advantages, studies highlight the potential of 3D pens as innovative tools for enhancing science education by transforming abstract concepts into tangible models and fostering hands-on learning. They enabled students to design and build scientific models without complex software, fostering creativity, problem-solving (Imeri et al., 2017), and understanding of molecular structures (Bernard & Mendez, 2020; Dean et al., 2016). They have shown to promote critical thinking and technical dexterity as students refined their models through observation and iteration (Takahashi & Kim, 2019). They were versatile, student-centered tools capable of strengthening visualization, spatial reasoning, and scientific literacy, making them valuable additions to 21st-century science classrooms (Bernard & Mendez, 2020).

As nations invest in advanced technologies and in line with global efforts to leverage 3D printing technologies in education and industry, the Philippines has initiated national programs to promote their development and use (Department of Science and Technology [DOST], 2019; Javier, 2025; Ugaldi et al., 2025). However, public awareness and utilization of 3D printing remain limited. This is particularly in education, where tools like 3D pens are still underexplored despite their commercial availability. Given this context, there is a pressing need to explore how these pens can be meaningfully integrated into science education, particularly in teacher training programs to prepare future educators for innovative, hands-on instruction. Addressing these gaps, this study highlights the integration of 3D pens in a local primary teacher education context, demonstrating their potential as accessible and engaging tools despite the global rise of 3D printing technologies. By examining the pre-service teachers' science skills development, perceptions, and problems encountered when using 3D pens to create educational models, this study provides valuable insights into how emerging technologies can be effectively leveraged in resource-constrained educational settings. This study seeks to enhance teacher preparedness, foster innovative and student-centered science instruction, and contribute to the broader discourse on contemporary science education.

Literature Review

Theoretical Framework

Visualization is critical in supporting the educational use of 3D pens, particularly in teacher training and science learning. Visualization is the cognitive process of forming mental representations of complex or abstract ideas to facilitate their easier comprehension, analysis, and communication (Mnguni, 2014). Typically, users use a pen or pencil as a medium for drawing two-dimensional (2D) visual representations. However, through 3D pens, users can bring their ideas to life in a 3D presentation while acquiring knowledge and developing their skills (Chen et al., 2021). The dual visualization and drawing process is essential in 3D pen use, where users must first mentally visualize the structure of their intended models before translating that vision into physical 3D structures. In the context of this study, such processes are directly linked to developing 21st-century and basic science process skills. Through 3D pen activities, pre-service teachers enhance their ability to represent abstract scientific concepts in concrete, visual forms, reinforcing their conceptual understanding and process skills.

Spatial thinking further enhances the effectiveness of 3D pen utilization among pre-service teachers. Users with strong spatial abilities are better equipped to interpret and generate spatial representations (Ishikawa & Newcombe, 2021) and comprehend visual-spatial relationships accurately (Rohmah et al., 2021). The exploratory, freehand nature of the pens allows users to test, revise, and innovate during the modeling process, which supports the study's goal of examining the pre-service teachers' perceptions and experiences using them. When using the pens, pre-service teachers must employ these spatial reasoning skills to plan, sequence, and construct 3D printed models, which are vital to developing scientific accuracy and model integrity. These processes foster scientific skills and relate to how participants perceive the pedagogical potential of the pens for primary science education, particularly in how such tools facilitate deeper student engagement and mastery of biology and chemistry.

To further contextualize how pre-service teachers integrate 3D pens in educational settings, the Technological Pedagogical Content Knowledge (TPACK) framework offers a comprehensive lens. The TPACK highlights the intersection of three core domains: technological, pedagogical, and content knowledge (Koehler & Mishra, 2009; Koehler et al., 2013), and is particularly useful in evaluating pre-service teachers' competence in using the pens. Within this framework, the use of the pens is situated as a technology-enhanced pedagogical strategy that allows

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users to design student-centered, hands-on science learning experiences aligned with content standards. From the technological knowledge (TK) perspective, pre-service teachers must learn how to operate, maintain, and troubleshoot the pens, which are relevant to understanding the problems encountered during use. Pedagogical knowledge (PK) involves knowing how to effectively integrate the pens into inquiry-based science instruction, foster engagement, and accommodate diverse learning styles, which are issues closely tied to pre-service teachers' perceptions of the pens. Content knowledge (CK) involves aligning the pen use with specific primary biology and chemistry topics that directly relate to the development of science skills. Meanwhile, the intersecting domains of technological pedagogical knowledge (TPK), pedagogical content knowledge (PCK), and technological content knowledge (TCK) provide deeper insights into the instructional decisions and challenges faced by pre-service teachers. TPK informs how they scaffold and assess 3D pen activities. PCK relates to their ability to teach science concepts using 3D printed models in the future. TCK emphasizes how the pens concretize abstract biology and chemistry content, reinforcing understanding and skill acquisition. These insights are crucial for interpreting the pre-service teachers' skills development, perceptions, and the problems they encountered.

Utilization of 3D Pens in Science Education

Growing evidence suggests that 3D pens can effectively enrich science learning. For instance, Imeri et al. (2017) observed that middle school students showed high enthusiasm for using 3D pens in STEM activities. They can immediately commence designing and fabricating their invention, even if they have no prior experience with 3D printing. The students acquired a variety of skills through hands-on learning and visualization. However, Imeri et al. (2017) noted that mastering the use of a 3D pen requires time and practice. They noted that the outputs were fragile, the pens posed burn risks, were prone to clogging, and were costly and environmentally unfriendly due to high filament use. Still, Imeri et al. (2017) concluded that the pens were suitable instruments for STEM education.

In chemistry, Dean et al. (2016) found that students experienced a high learning curve when using 3D pens to design molecular models. Students could only create at least two models within a given period, indicating that accuracy and time constraints affected the model-making process. The models were relatively fragile, with durability depending on the amount of filament used. Even so, Dean et al. (2016) emphasized that 3D pens are powerful tools for teaching and learning. Similarly, Bernard and Mendez (2020) found that young students could efficiently create molecular models using 3D pens and templates, describing the activity as user-friendly, enjoyable, and engaging. The students can efficiently operate and accurately complete a model. However, Bernard and Mendez (2020) noted that precise modeling was limited by the pen's manual, freehand nature, and warned of burn risks from the heated nozzle. Students also encountered technical issues, including filament blockages, burning plastic odor, and power interruptions. Models drawn with acrylonitrile butadiene styrene (ABS) filament often stuck to the templates due to its high melting point. Bernard and Mendez (2020) recommended using polylactic acid (PLA) filaments for easier removal due to their lower melting point.

Expanding on these findings, Chen et al. (2021) observed significant improvement in primary students' abilities. The students demonstrated a high level of concentration, becoming adept with the pens and able to continually adjust the model based on flaws in the final output when printing. Their spatial thinking capacity has improved, allowing them to design models in their minds using the teacher's description and 3D pens. The students' personalities were further developed, allowing them to express their ideas and create outstanding models. In a related study, Takahashi and Kim (2019) found that students struggled with using the 3D pen due to issues with stroke direction and speed, and difficulties with filling, bonding, and stringing. Students detailed that their designs had bumpy and bloated textures, filling the large surface gaps in the designs was exhausting, bonding the designs to create a final 3D piece was difficult, and the extruded filament created unwanted strings that needed to be removed continually. Nevertheless, the students developed effective techniques, including button control, using stencil templates and tweezers, and drawing and assembling parts piece by piece. Convincingly, Takahashi and Kim (2019) demonstrated that using 3D pens facilitated concept validation and exploration for students, allowing them to manipulate and create ideas in physical form directly.

Primary Science Education and Pre-service Teaching in the Philippines

The formal inclusion of science subjects in the Philippines begins in Grade 3. This is reflected in the Kindergarten to Grade 12 (K-12) Curriculum and the newly reformed MATATAG Curriculum mandated by the Department of Education (DepEd). The MATATAG revises the Kindergarten to Grade 10 (K-10) curriculum and is still on its pilot

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implementation stage. It is an acronym based on: MAke the curriculum relevant and up-to-date; TAke steps to improve access to quality basic education; TAke care of learners through inclusive and positive learning environments; and Give support to teachers for better instruction (DepEd, 2023). The science curriculum in both the K-12 and MATATAG curricula follows a spiral progression, where concepts and skills are revisited with increasing complexity. Learning is hands-on and skill-integrated, emphasizing real-world applications, interdisciplinary connections, and the development of scientific attitudes and reasoning (Canuto & Espique, 2023; DepEd, 2016, 2023).

Given these curricular structures, teachers must employ diverse, skill-integrated, and hands-on strategies that highlight science's connections with other disciplines (Canuto et al., 2024; Choycawen et al., 2024; Fabillar et al., 2024). This is why pre-service teachers enrolled under the Bachelor of Elementary Education (BEEd) program are trained to become competent in content and pedagogy, as mandated by the Commission on Higher Education (CHED). They must demonstrate strong pedagogical and content knowledge, higher-order thinking skills (HOTS), and effective use of information and communication technologies (ICTs). This involves staying updated on educational trends, applying emerging technologies, and guiding students in using technology (Canuto, 2023; CHED, 2017). In this manner, science courses for BEEd pre-service teachers emphasize spiraling basic science concepts based on the K-12 and MATATAG curricula, their applications, and effective teaching strategies, including the development of instructional materials, assessments, and technology-based activities.

With these curricula and competencies in mind, this study involved BEEd pre-service teachers using 3D pens to create 3D printed models focused on biology and chemistry lessons across Grades 3 – 6. They freely selected suitable topics, including living things, plant and animal functions, body systems, and organism interactions for biology, and materials, mixtures, changes, and simple reactions for chemistry (DepEd, 2016, 2023). Given these topics, the pre-service teachers' use of 3D pens in this study was a purposeful choice. The use of the pens allowed them to transform abstract concepts into tangible, manipulable models, aligning with the science curriculum's emphasis on inquiry-based learning and model use. Thus, integrating the pens not only supported the development of science concepts but also served as a professional training activity that bridged theory and practice in science teaching.

Research Gap

Despite the expanding global adoption of 3D printing technologies and national efforts in the Philippines to advance them (DOST, 2019; Javier, 2025; Ugaldi et al., 2025), a significant technological gap remains in awareness and utilization of these tools, particularly 3D pens, in educational settings. Despite its potential to foster creativity, hands-on learning, and active student engagement, the affordable and user-friendly 3D pen has received limited empirical investigation in classroom settings (Chun, 2021). Existing studies emphasize technology-driven instructional models rather than exploring how these pens might support student-centered experiences. Although the potential of the pens to enhance STEM learning among students is recognized (Bernard & Mendez, 2020; Chen et al., 2021; Dean et al., 2016; Imeri et al., 2017), research focusing specifically on pre-service teachers' preparedness to integrate these tools in primary science education effectively remains scarce, presenting an empirical and knowledge gap. Most literature focuses on student outcomes or general technological competencies, with limited exploration of how BEEd pre-service teachers utilize 3D pens as innovative educational materials for primary biology and chemistry lessons, which are anchored in visualization, spatial thinking, and the TPACK framework. Specifically, the overall experience of primary pre-service teachers in using the pens receives no attention in teacher training programs. Addressing these gaps is essential to equip future educators with the confidence and skills to foster creativity, critical thinking, and hands-on learning aligned with 21st-century science education goals.

Research Significance

This study on the use of 3D pens among primary pre-service teachers is significant as it investigates an innovative, hands-on approach to enhancing science education through emerging technologies. By integrating the pens into teacher training, the study bridges the gap between theoretical knowledge and practical classroom application, enabling pre-service teachers to represent complex biology and chemistry concepts in tangible, visual forms. The study highlights how 3D pens facilitate the development of scientific process skills, pedagogy, and educational tools in science. These instructional benefits contribute to pre-service teachers' readiness to implement engaging and student-centered science lessons in their future teaching profession. Additionally, the study demonstrates

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how the pens can facilitate interdisciplinary collaboration, expand instructional possibilities beyond traditional approaches, and enhance content understanding. It further emphasizes the importance of technological fluency in teacher preparation and underscores the need for educators to adapt to the evolving educational landscape. By focusing on the skills, perceptions, and problems experienced by pre-service teachers, this research advances science education. It supports the broader goal of cultivating scientifically literate and technologically competent future educators.

Research Aims and Research Questions

This study examined the perceptions and experiences of BEEd pre-service teachers using 3D pens to create 3D printed models for primary biology and chemistry education. It aimed to evaluate their development of 21st-century and basic science process skills after using the pens and making models. It also aimed to examine the participants' perceptions towards the potential use of the pens as educational materials for primary biology and chemistry lessons. Additionally, it aimed to determine the problems they encountered in using the pens. The following questions guided the study:

1. What is the level of agreement among pre-service teachers regarding their enhanced scientific skills after using 3D pens to create 3D printed models related to primary biology and chemistry lessons?
2. What is the level of agreement among pre-service teachers regarding the potential use of 3D pens as educational materials in primary biology and chemistry lessons?
3. What are the problems experienced by the pre-service teachers when using 3D pens?

Research Methodology

Design

The study employed a sequential explanatory mixed-methods design, which integrates quantitative and qualitative research elements (Draucker et al., 2020; Schoonenboom & Johnson, 2017). The study's initial phase involved collecting and analyzing quantitative data through a self-developed questionnaire. This was followed by the subsequent phase of collecting and analyzing qualitative data gathered through semi-structured interviews, which were informed by the findings obtained from the quantitative analysis. Specifically, for the quantitative phase, descriptive statistics were used to examine the pre-service teachers' experiences regarding the development of 21st-century skills and basic science processes, and their conception of the advantages and impact of 3D pens on science instruction. Their struggles in using the pens were also included. For the qualitative phase and to deepen the understanding of these experiences, the interview results were examined using manual thematic analysis to provide a structured understanding and interpretation of the content supporting the pre-service teachers' experiences. It involved categorizing excerpts in the transcribed data to support the themes (Proudfoot, 2022) of skills development, problems experienced, and perceptions towards 3D pens among the participants. The study was conducted from May to July 2025.

Participants

The study participants were 34 pre-service teachers enrolled in the BEEd program in one of the campuses of a state university in the Cordillera Administrative Region (CAR), Philippines. Table 1 presents the full demographic distribution of the participants. In terms of gender, 5 (14.71%) were males and 29 (85.29%) were females. Regarding year level, 11 (32.35%) were in their first year, 13 (38.24%) in the second year, and 10 (29.41%) in the third year. The first- and second-year students were enrolled during the second term, while the third-year students participated during the third term of Academic Year (AY) 2024 – 2025. All 34 pre-service teachers were included in the survey during the quantitative phase. However, only 21 of them willingly participated in the qualitative phase. The pre-service teachers were assigned pseudonyms, from P1 to P34. The same assigned pseudonyms were used in the survey and interviews. The small number of participants reflected the campus's modest population, which is one of the smallest among the state university's campuses. However, this number of participants was advantageous, allowing for the in-depth analysis of the pre-service teachers' experiences using 3D pens. This number also presented practical necessity, such as the cost-effectiveness of individual pens among the participants and the

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effective mitigation of potential risks. It also allowed close monitoring of the pre-service teachers and immediate maintenance of the pens.

Table 1
Profiles of the BEEd Pre-service Teachers

Profiles	*N*	%
1. Gender		
A) Males	5	14.71
B) Females	29	85.29
2. Year level		
A) 1st year	11	32.35
B) 2nd year	13	38.24
C) 3rd year	10	29.41

Materials and Instruments

The study utilized 20 sets of the 3DPen-2, as it was the most commercially available in the country. Each set came with a pre-selected colored 3D pen and assorted filaments. Each pen featured an inbuilt liquid-crystal display (LCD), a 0.7 mm nozzle, and adjustable temperatures from 160 °C to 230 °C for 1.75 mm filaments. When powered on, the pen preheats before the filament is fed through the port into the nozzle, where it melts and extrudes to form 3D shapes. The filament cools and hardens upon dispensing, and pressing the feed button again disengages it after use. The PLA and ABS filaments, being the most common and compatible materials, were used in conjunction with the pens. PLA, known for its low melting point (Bernard & Mendez, 2020), biodegradability, and low toxicity (Iftekar et al., 2023; Liu et al., 2019), is commonly used for do-it-yourself (DIY) projects, household items, and prototyping. In contrast, ABS offers superior mechanical strength, making it suitable for products that require high impact, abrasion, and heat resistance, as well as durability (Iftekar et al., 2023; Moradi et al., 2022). In addition, glossy photo paper was used as a drawing template due to its affordability and smooth, coated surface, which prevented filaments from sticking permanently and allowed for easy removal of the model. Its white, reflective finish enhanced filament visibility for accurate tracing, while its thickness and rigidity prevented curling or tearing during use.

To gather quantitative data, the study employed a self-developed questionnaire comprising four parts. The first part comprised the pre-service teachers' profiles. The second part consisted of two categories of scientific skills to assess the degree of skill development in pre-service teachers after using the 3D pens, which were evaluated using a 4-point Likert scale. The first list of scientific skill categories comprised the 21st-century skills, including critical thinking, creativity, collaboration, and communication skills, or the four C's, including technological skills. The other category consisted of a list of scientific skills in the basic science process, which included skills in classification, measurement, and inference. Communication, one of the basic science process skills, was already integrated into 21st-century skills. The third part consisted of 10 items to assess participants' perceptions of their overall use of the pens, which were also evaluated using a 4-point Likert scale. The statement regarding perceptions was derived from relevant literature that summarizes the benefits of using the pens in education. The last part included 30 items further divided into two problem categories that have affected the participants' experiences, allowing them to select more than one item. The first category consisted of 20 items related to technical issues, including functionality, performance, and usability of the pens. On the other hand, the second problem pertained to the 10 items related to pedagogical issues regarding the integration of the pens into the teaching and learning process. These issues were derived from the problems experienced by users in the literature.

The Likert scale used for both skills development and perception was designated as follows: 1 = Strongly Disagree (SD), 2 = Disagree (D), 3 = Agree (A), and 4 = Strongly Agree (SA). Meanwhile, interview guide questions were used to gather qualitative data. This ensured a structured and systematic approach, allowing the researchers

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to stay on track and cover all relevant topics and questions related to the research objectives. This also explored the depth and breadth of the quantitative responses gathered.

Validity and Reliability

For the quantitative data, the questionnaire was validated by three professional teachers, two university instructors, and one primary science teacher, all of whom have experience in 3D printing technologies or educational technology courses for teacher training programs. The survey was determined to have a mean score of 3.86, indicating high construct validity. A pilot test involved a separate, collective group of 30 Campus alum teachers with a similar degree. They were invited to the campus for orientation and training on using the 3D pens, which they practiced with for 10 – 12 hours before completing the survey. As a result, the internal consistency of the survey instrument was assessed using Cronbach's alpha, which yielded an overall value of .70. This indicated an acceptable level of reliability, suggesting that the items on the survey were sufficiently correlated and measured the same underlying construct. However, it was determined that two items from the survey must be removed due to their low internal consistency. Specifically, the items removed were the 'Observation' and 'Prediction' under the basic science process skills category. Moreover, the pilot test helped identify pens with technical issues, which were then replaced with functional ones to reduce participant risks and minimize technical problems during use.

On the other hand, to ensure the validity and reliability of the qualitative data, the study employed multiple strategies to establish the trustworthiness of the findings, guided by the criteria of credibility, transferability, dependability, and confirmability (Nowell et al., 2017). The semi-structured interview questions were carefully crafted based on the quantitative survey. The three teachers who validated the survey questionnaire also validated the guide questions. This ensured that the guide questions were appropriate, clearly worded, and targeted the intended constructs related to scientific skill development and perceptions of 3D pen use, thereby addressing encountered problems and supporting construct validity.

To enhance credibility, the interviews were conducted in a supportive environment, allowing pre-service teachers to speak freely and reflectively about their experiences. In adherence to the bracketing principle, the researchers consciously set aside personal beliefs and potential biases during data collection and analysis, maintaining neutrality throughout the process. After each interview, the transcription and translated responses were returned to the participants for member checking, allowing them to confirm the accuracy and authenticity of their statements. This step ensured that the meanings conveyed in the English translations genuinely reflected the participants' intentions, particularly since most interviews were conducted in Filipino or the local languages.

Additionally, the researchers engaged a qualitative research expert to independently verify the coding and thematic analysis, ensuring dependability and confirmability. The expert cross-checked the codes, categories, and emerging themes to ensure consistency, alignment with the raw data, and representation of the participants' experiences. An audit trail documenting key decisions during analysis was also maintained, promoting transparency and accountability. For transferability, rich descriptions of the research setting, participants, and procedures were provided, allowing others to assess the relevance and applicability of the study to similar educational contexts. Confirmability was further ensured through verbatim transcription, consistent analytical procedures, and the inclusion of representative participant quotations. Translations were also reviewed by a multilingual language expert familiar with the local, Filipino, and English languages, reinforcing linguistic fidelity. Together, these integrated strategies established a strong foundation of rigor in the qualitative phase.

Procedures

Following the sequential explanatory design, the study commenced in several phases. These phases were undertaken with consideration for the participants' firsthand exposure to the 3D pens, ensuring their safety and providing comprehensive study results. The pre-service teachers were divided into three groups based on their year levels for convenience and focused sessions. Each group was invited and scheduled for focus sessions over three consecutive days, lasting approximately four hours daily. Overall, they utilized the pens for 12 hours, from orientation to 3D printed model-making.

First, the pre-service teachers participated in a 3D pen introduction session that lasted approximately an hour and a half. This included orientation on the types of filaments, parts of the pens, and practice on how to use the pens. They were provided with various filaments and glossy photo papers. They sketched basic 2D shapes as part of their practice. Supplementary video instructions on how to use the pens and basic model-making were

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also provided. Second, the pre-service teachers practiced designing and creating 3D printed models based on their ideas, which lasted another hour and a half. This phase ensured that pre-service teachers were familiar with and had mastered the use of the pens. Third, the pre-service teachers were required to create 3D printed models that could be used as educational materials for primary science education. The designs of the models were based on the K-12 and MATATAG science curricula, allowing them to choose from the fields of biology and chemistry. They could create as many models as possible, as long as filaments were available. This enabled the pre-service teachers to be accustomed to using the pens to create educational materials that support science learning. This model-making phase lasted for about nine hours.

Fourth, at the end of three focused sessions for each group, the researchers personally gave the pre-service teachers the questionnaires to gather quantitative data. The pre-service teachers completed the survey in approximately ten minutes. The questionnaires were retrieved immediately. Lastly, for the qualitative data, a semi-structured interview was conducted following the quantitative data tabulation and analysis. The interviews lasted approximately 20 – 40 minutes and were conducted in person, with recordings made using smartphones. Interview schedules and venues were arranged in advance, and all interviews were transcribed verbatim. Since most responses were in local or Filipino languages, they were translated into English and verified by a language expert proficient in both. A manual thematic analysis was employed to identify emerging themes.

Before the study was conducted, letters asking for approval were sent to the state university officials. It outlined the scope of the study and the involvement of BEEd pre-service teachers on a campus. Then, an informed consent letter was sent to the pre-service teachers, requesting their voluntary participation and informing them of their right to withdraw from the study without repercussions. It provided the reason for their vital contribution to the study, the estimated time of participation, the in-person giving of questionnaires, and the conduct of interviews. A section of the letter outlined the probable benefits that pre-service teachers may gain as participants. These included preparing for professional careers, developing pedagogical knowledge and instructional strategies, engaging in hands-on learning using 3D pens, increasing technological literacy, developing and enhancing scientific skills, and assessing interdisciplinary science education at the primary level.

Since the participants were grouped accordingly, each pre-service teacher was lent an individual 3D pen. The pens were returned after every focused session for maintenance and repair. The pre-service teachers were given individual face masks and cotton gloves, which they used during orientation, training, practice, and model-making. They were advised to seek immediate medical attention from the campus nurse if they were exposed to any health or physical risks from using the pens.

Data Analysis and Management

The researchers gathered the data personally to ensure well-documented, systematic, and rigorous data collection. Responses from the questionnaires were organized and presented through tabulations. The recorded interviews were transcribed, translated, and manually thematized. Each recorded interview was assigned codes based on the participants' pseudonyms. All raw data from the questionnaire and recorded interviews were stored and used strictly for this study. Frequency (f), mean (M), and standard deviation (SD) were used to analyze the pre-service teachers' skills development and perceptions regarding 3D pens. A statistical limit was used for skills development and perceptions, comprising 1.00 – 1.75 = Strongly Disagree (SD), 1.76 – 2.50 = Disagree (D), 2.51 – 3.25 = Agree (A), and 3.26 – 4.00 = Strongly Agree (SA). Percentages (%) and ranking were used to examine the problems encountered by the participants when using the pens. The findings from the interviews were analyzed using deductive theme analysis to substantiate the pre-service teachers' experiences, including their skills development, problems encountered, and perceptions regarding the pens.

Ethical Considerations

The study upheld established ethical protocols to ensure the rights, safety, and well-being of all participating institutions, researchers, and pre-service teachers. Before data collection, the research underwent ethical review and received formal approval. Approval was also secured from the institution where the study was conducted. Informed consent was obtained from all participants, clearly explaining the study's purpose, procedures, potential risks, and their voluntary involvement. Participants were assured that they could withdraw from the study at any time without penalty or consequence. To ensure anonymity, participants' identities were protected using pseudonyms, with no personal identifying information disclosed. Confidentiality was maintained by storing raw and processed

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data in a password-protected computer accessible only to the researchers. The informed consent form specifically outlined the health and physical risks of using 3D pens. It recommended safety measures, including the use of face masks and gloves. The researchers regularly maintained the equipment and closely monitored participants to minimize risks. Participants were encouraged to communicate any concerns, which were promptly addressed. Transparency was maintained by informing participants of the research objectives, procedures, and outcomes, while ensuring strict confidentiality and privacy.

Research Results

Quantitative Results: Scientific Skills Developed by the Pre-service Teachers After Using the 3D Pens

Overall, the pre-service teachers agreed on the skills they developed concerning using the 3D pens, as shown in Table 2. They strongly agreed on creativity and technological skills in the 21st-century skills. They also agreed they had developed critical thinking, communication, and collaboration skills. Likewise, they agreed on their developed basic science process skills in measuring, classifying, and inferring.

Table 2
Scientific Skills Developed by the Pre-service Teachers After Using the 3D Pens

Scientific Skills	*M*	*SD*	Descriptive Equivalent
A. 21st Century Skills			
1. Technological skills	3.63	0.48	Strongly agree
2. Critical thinking	3.25	0.43	Agree
3. Creativity	3.81	0.39	Strongly agree
4. Collaboration	3.06	0.61	Agree
5. Communication	3.09	0.63	Agree
B. Basic Science Process Skills			
1. Classification	3.03	0.53	Agree
2. Measurement	3.13	0.65	Agree
3. Inference	3.03	0.64	Agree
Overall mean	3.25	0.62	Agree

Perceptions of the Pre-service Teachers Regarding the Potential Use of 3D Pens as Educational Materials for Primary Biology and Chemistry Education

Table 3 shows the pre-service teachers' perspectives towards the pens. Overall, they strongly agreed on the potential use of the 3D pens as educational materials for primary biology and chemistry education. Surprisingly, they strongly agreed with the pens' instant 3D printing of objects, achieving a perfect mean score. They also strongly agreed on the pens' support for interdisciplinary learning, their potential to stimulate and engage, their use in science learning, their ability to explore and validate scientific ideas, and their facilitation of the freeform creation of 3D designs. They agreed on the pens' lasting impact on learning, convenience and ease of use, accessibility and portability, and visualizing ideas and turning them into 3D printed models.

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Table 3

Pre-service Teachers' Perceptions Regarding Using 3D Pens as Educational Materials for Primary Biology and Chemistry Education

Perceptions	*M*	*SD*	Descriptive Equivalent
1. 3D pens are accessible and portable to use.	3.03	0.17	Agree
2. 3D pens are convenient and easy to operate.	3.16	0.36	Agree
3. 3D pens allow instant creation of 3D printed objects.	4.00	0.00	Strongly Agree
4. 3D pens allow direct and freehand manipulation of designs.	3.38	0.48	Strongly Agree
5. With 3D pens, I can visualize ideas and easily create 3D printed objects and models.	3.00	0.56	Agree
6. 3D pens are stimulating, motivating, and engaging.	3.69	0.46	Strongly Agree
7. 3D pens are significant and can potentially support science learning and primary science education.	3.56	0.61	Strongly Agree
8. 3D pens enable exploration and validation of scientific ideas.	3.41	0.61	Strongly Agree
9. 3D pens can provide opportunities for interdisciplinary learning between science and other subjects.	3.72	0.45	Strongly Agree
10. 3D pens have an enduring impact on learning acquisition.	3.19	0.39	Agree
Overall Mean	3.41	0.55	Strongly Agree

Problems Experienced by the Pre-service Teachers When Using the 3D Pens

As gleaned in Table 4, the dependence of the 3D pens on being continuously plugged in is the topmost technical issue encountered by the pre-service teachers. The second most ranked issue is the frequent refilling of filaments. Third and fourth, with the same ranks, are creating models with fine, accurate details and the unpleasant smell of filaments. Fifth is the creation of large-scale models. They encountered the fewest problems regarding the filaments' stickiness from the templates. They also experienced the fewest issues with the filaments' hardening time, nozzle blocking, supply, and the template's surface, all with the same ranks. Additionally, the lack of skills and practice in using the pens emerged as the most pedagogical issue they experienced. This is followed by time constraints and mastering techniques for finer, precise models. With the lowest ranks, they encountered issues relating to the pens' stimulating and engaging use, including the conduciveness of the working space.

Table 4

Problems Experienced by the Pre-service Teachers When Using the 3D Pens

Problems	*f*	%	*Rank*
A. Technical Issues			
1. The 3D pens are not functioning well or are not turning on.	8	23.53	14
2. 3D pens do not support the drawing of straight and symmetrical lines.	24	70.59	6
3. Achieving fine details and precision of the designs can be difficult with 3D pens.	27	79.41	3
4. Creating a whole 3D printed object/ model is time-consuming.	16	47.06	10
5. The created 3D printed objects/ models are not sturdy or durable enough.	19	55.88	9
6. Large-scale 3D printed objects/ models are hard to create using 3D pens.	25	73.53	5
7. The 3D pen extrudes filament unevenly, resulting in an inconsistent print quality.	16	47.06	10
8. The heated filaments coming out of the nozzle create unwanted strings.	20	58.82	8
9. The filaments took time to harden.	4	11.76	16

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Problems	*f*	%	*Rank*
10. The filaments are sticky and hard to detach from the templates.	2	5.88	20
11. The filaments keep blocking the nozzle.	4	11.76	16
12. Most of the time, the filaments need to be replaced.	29	85.29	2
13. The heated filaments produce an unwanted smell.	27	79.41	3
14. The drawn designs are difficult to interconnect or adhere to surfaces.	24	70.59	6
15. The heated nozzle presents risks of skin burn.	16	47.06	10
16. There is not enough supply of filament.	4	11.76	16
17. 3D pens need to be constantly plugged into a power supply.	31	91.18	1
18. The surfaces of the templates and other objects affected the structure's design.	4	11.76	16
19. 3D pens need to be constantly maintained and cleaned.	8	23.53	14
20. The templates provided are insufficient or lack representation of objects.	12	35.29	13
B. Pedagogical Issues			
1. The instructor lacks training and support.	4	11.76	7
2. There is not enough constructive feedback from the instructor.	12	35.29	4
3. There is not enough time allocated for using the 3D pens.	21	61.76	2
4. It is difficult and frustrating to use and operate 3D pens.	4	11.76	7
5. The 3D pens are not stimulating or engaging enough to use.	3	8.82	9
6. I lack certain skills and practice to create precise and detailed 3D printed objects/ models.	25	73.53	1
7. Choosing specific topics where the 3D pens will be integrated is difficult.	12	35.29	4
8. There are not enough activities that encourage me to think critically and use the 3D pens to create objects or models.	8	23.53	6
9. The working area/ space is not conducive to 3D printing.	3	8.82	9
10. I find it challenging to master the techniques required to create precise and detailed 3D printed objects/ models.	20	58.82	3

Qualitative Findings

The summarized findings in Table 5 represent the emerging themes derived from interviews with 21 pre-service teachers. The themes are categorized under each research question: 1) pre-service teachers' scientific skills, 2) their perceptions on the potential use of 3D pens for primary biology and chemistry lessons, and 3) problems experienced in using the pens to create 3D printed models.

Table 5
Overview of Themes Emerging from the Interview Responses of Pre-service Teachers

Main Themes	Sub-themes
1. Scientific skills developed after using the 3D pens	a. Acquired technological skill b. Enhanced creativity c. Improved critical-thinking d. Fostered communication and collaboration e. Reliance on visual measurement estimation f. Moderately enhanced classification and inference

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2. Perceptions regarding the potential use of 3D pens as educational materials for primary biology and chemistry lessons	a. Instant tangible models b. Potential as creative and interdisciplinary science teaching tools c. Ease of use and accessibility d. Engagement and motivation in learning
3. Problems experienced when using the 3D pens	a. Nature of the 3D pens b. Nature of the filaments c. Skill and mastery issues d. Time constraints e. Precision and quality in designs f. Materials and resource constraints g. Lack of instructional support

Scientific Skills Developed After Using the 3D Pens

Acquired Technological Skill. Most pre-service teachers strongly agreed that they had acquired technological skills after using the 3D pens. They shared a progression in their understanding and ability to operate the pen, despite having no prior exposure. Using the pen facilitated the development of their basic technological literacy. They shared,

P12: *"I had never used a 3D pen before. It is my first time handling such technology. I do not know how to use the pen…but I felt confident in using it to create models after a session."*

P5: *"…I learned how to use the 3D pen, like adjusting the heat and inserting the filaments. I think I gained enough technological skill to use it."*

P18: *"…I have never heard of 3D printing or 3D pen…At first, I did not know how to turn it on. I also do not know what the other buttons do or what the filaments are for. But, as I used the pen, I gained basic technological knowledge for operating it."*

Enhanced Creativity. The pre-service teachers indicated that using the 3D pen stimulated their imaginative thinking and enhanced their creativity. It enabled them to be more creative in some science concepts. They highlighted how the pen allowed them to bring their ideas and imagination to life. Also, they noted that the experience inspired new approaches to instruction. They expressed,

P19:*"I could draw the objects I have imagined using varied filament colors."*

P12:*"The pen helped me be more creative in drawing science concepts..."*

P18:*"…the pen helped me think in a new way in preparing my future lessons."*

Improved Critical-thinking. The 3D pens fostered the pre-service teachers' critical thinking skills. It required them to make strategic decisions about design structure, sequence of construction, and filament usage. It demanded foresight, structured planning, and critical decision-making. Some pre-service teachers mentioned,

P21: *"Using the pen was not just about drawing…it required me to think and decide carefully on what model I should draw… so that filaments will not be wasted."*

P10: *"…creating science models using the 3D pens was not easy. I had to plan my design first and then think about how the drawing would combine to represent the science models I wanted."*

Fostered Communication and Collaboration. Collaborative work and meaningful communication were encouraged among the pre-service teachers. They could communicate ideas with their peers to co-create models, divide responsibilities, and share feedback to improve their outputs. Some sought input from their classmates to refine their models. Some collaborated with others to finish a complex design. Some cited,

P2: *"I was able to describe my drawn designs to my classmates…and I asked for their comments to improve them."*

P19: *"…I worked with my classmates. I made the flower petals while they made the stem and the flower pot. The combined model was not perfect, but I worked with others to easily finish a flower model."*

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Reliance on Visual Measurement Estimation. Although rulers were occasionally used, some pre-service teachers relied on visual estimation. They found rulers impractical for the freeform nature of 3D pen designing and instead relied on estimation. This led to unrefined model outputs. They conveyed,

P18: *"Sometimes, I used a ruler while drawing the objects. However, most of the time, I estimate the sizes and shapes…making my models asymmetrical."*

P9: *"Using a ruler was not practical…I mostly estimate the sizes of the designs while drawing…It is something I did not expect when using the pens."*

Moderately Enhanced Classification and Inference. While some pre-service teachers noted that some skills were not highly developed in using the 3D pen, they still engaged in inferring and classifying skills to support the design and execution of their models. They described the need to anticipate their models' outcome mentally, indicating inferential thinking. Although not deeply emphasized, classification was still present in the planning stages as they broke down models into manageable parts. Some pre-service teachers pointed out,

P18: *"…classifying and inferring was not greatly developed using the pen…Though I can say that I did have to classify into sections the parts of the models that I have to draw…"*

P21: *"I had to infer how the model would look once I finished drawing…it helped me visualize the final model and plan accordingly."*

P12: *"I have to imagine the result before I work on my drawings. I had to guess what the model would look like before I started to draw."*

Perceptions Regarding the Potential Use of 3D Pens as Educational Materials for Primary Biology and Chemistry Lessons

Instant Tangible Models. The pre-service teachers described their experiences as fulfilling due to the 3D pen's ability to translate their ideas into tangible outputs instantly. Accordingly, the pens offered a unique blend of immediacy, simplicity, and creative control. The pens captured their sense of wonder, satisfaction, and ability to draw and create models simultaneously. These are reflected in the following responses,

P4: *"…I was amazed…I liked how I could create a 3D printed object right away."*

P13: *"Seeing the object appear as I drew it was satisfying."*

P14: *"The 3D pen allowed me to immediately create the model I imagined without using complex machines or software."*

P1: *"The 3D pen let me draw and build at the same time…like creating models on the spot."*

Potential as Creative and Interdisciplinary Science Teaching Tools. The pre-service teachers shared the educational potential of 3D pens for teaching scientific concepts, particularly in ways that promote visualization, creativity, and interdisciplinary learning. They indicated the value of the pens in fostering creative engagement with science and supporting abstract and conceptual science ideas. Its interdisciplinary potential with other subjects was also disclosed. The pre-service teachers said,

P1: *"I think it is a great tool to introduce scientific concepts in a creative way…such as in a lesson related to animals not found in the locality."*

P7: *"…aside from pictures and videos, I think I can use the 3D pens later on to explain topics like cells or atoms easily…these are some topics that are hard to imagine…"*

P10: *"I could see immediately if my model was scientifically accurate or if I needed to adjust it."*

P14: *"I can see how 3D pens can connect science with other subjects, such as math and the arts."*

Ease of Use and Accessibility. User-friendliness, accessibility, and practicality are some of the common responses from pre-service teachers regarding the use of 3D pens. They pointed out the pen's intuitive design, minimal setup requirements, and affordability. Using the pen, especially for first-timers, required little time or prior experience to operate effectively. They added that the pen does not demand specialized infrastructure to operate. They shared,

P15: *"We did not need a large setup in the computer lab…we were provided with tables and extension wires…I just plugged the pen, turned it on, and started using it."*

P8: *"The 3D pen was light and easy to carry…it just looked like a big electrical pen."*

P6: *"…it is less complicated than I thought…I just plugged it in, waited for it to heat, and started drawing immediately."*

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P18: *"It was simple to control, even though it was my first time using one…it was easy to use because the button controls were straightforward."*

P14: *"I searched and found that the 3D pens are readily available in online stores… their prices also seemed affordable for a future teacher."*

Engagement and Motivation in Learning. The pre-service teachers revealed a strong and consistent increase in engagement, enjoyment, and intrinsic motivation while using 3D pens for science-related model-making. The hands-on pen activities sustained their attention and kept them actively involved and focused on the modeling process. They were excited, could enjoy using the pens, and experienced less stress. As they highlighted,

P12: *"I did not feel bored when using the 3D pens…I enjoyed drawing science models…"*

P5: *"I stayed focused because I was really interested in what I was drawing."*

P11: *"I was excited to use the pens because it was something new and different…"*

P17: *"…the 3D pen made the model-making more enjoyable and less stressful."*

P9: *"I enjoyed drawing models…seeing my imagination come to life made me happy."*

Problems Experienced When Using the 3D Pens

Nature of the 3D Pens. While using the 3D pens presented engaging and creative opportunities, several pre-service teachers identified practical limitations related to the pen's nature that affected their overall experience. One of the most commonly cited limitations was the reliance on electricity, which restricted 3D pen use. The need to constantly plug in the pen was a prerequisite. One pre-service teacher cited,

P3: *"I cannot use the 3D pens without electricity. It needed to be plugged in all the time."*

Some pre-service teachers reported fast consumption of filaments. This required regular replacement and careful preparation. One of them shared,

P21: *"The filaments were easily consumed and must be refilled most of the time. Rolls of filaments should be prepared before starting to draw."*

Another recurring issue was the problem of designing complex or larger models. A pre-service teacher noted that they typically created smaller models with unrefined surfaces. They shared,

P18: *"It was difficult to create big models with flawless design…I usually do small models with rough textures."*

Some pre-service teachers identified a limitation in geometric precision when using 3D pens. This is particularly true when creating straight lines and edges. They preferred curvilinear or freeform designs. They cited,

P12: *"I prefer to create curvy models…it was difficult to draw straight lines with the pens."*

P7: *"Though straight edges were impossible to draw perfectly, they were better in connecting…"*

The pre-service teachers highlighted a critical safety concern when using a 3D pen. There was a safety risk due to the pen's exposed hot nozzle, which poses a potential risk of burns or discomfort even when basic protective measures were used. One expressed their concern,

P18: *"I can feel the hot end of the pen even if I am wearing cotton gloves…I was very aware not to touch the hot-end…"*

The pre-service teachers noted inconsistencies in filament output depending on the flow speed settings. They observed that the flow speed directly influenced the thickness of the extruded filament, thereby affecting the thickness of the model layers. They raised concerns about the model's durability, specifically how it is affected by the number of filament layers. They validated,

P4: *"Sometimes the 3D pens extrude thin filament lines, especially if the control flow was slower. But if I made it flow faster, the filaments were thicker."*

P16: *"…to have even thicker filament lines, I use the fast flow…Though I need to have a longer filament roll since it easily consumes it."*

P2: *"…models with thinner filament layers were easy to bend and break."*

Nature of the Filaments. Regarding the nature of the filaments, a notable concern raised by the pre-service teachers pertains to the odor emissions from the heated filaments. This filament-related smell, especially when using ABS filaments, was reported as a source of discomfort and distraction. These concerns are underscored by the following,

P18: *"…ABS filament produced a more irritating smell...Thankfully, I am wearing a face mask."*

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P20: *"The filament smell was unpleasant and distracting."*

Some of the pre-service teachers observed filament stringing. They observed that residual material continued to stretch and form thin, web-like threads when the filament was extruded. This was especially during transitions between drawing points or when the pen was lifted from the surface. One described,

P21: *"…just like a glue gun, the filaments coming out of the pens created spiderweb-like strings…"*

Skill and Mastery Issues. Several pre-service teachers identified that they had prior difficulties using the 3D pens due to unfamiliarity, lack of skills, and a need for sustained practice in using the pens effectively. While the pen offered creative opportunities, becoming competent in its use was not immediate. They revealed,

P1: *"Well, it is my first time using a 3D pen…I do not know how to manipulate it at the beginning."*

P8: *"Even if we had training and practice sessions, I still feel that I lack the necessary skills in using the pens."*

P13: *"It was hard to control the pen for detailed designs without much practice."*

Time Constraints. The pre-service teachers raised their concern about the unexpectedly long duration required to complete even simple 3D pen models. They encountered time constraints and a long duration to create a model, requiring significant time investment. Some of them signified,

P11: *"…it took me more than an hour to create a simple model."*

P6: *"Making even a simple model took much longer than I expected."*

Precision and Quality in Designs. Precision, design quality, and durability are other issues raised by the pre-service teachers. There was user frustration stemming from the design intention and the accuracy of the actual model output. They also identified the bonding of parts and the fragility of the models. The following responses reflect this,

P19: *"It was frustrating not being able to make my designs as precise as I imagined."*

P2: *"The objects I created were fragile, and sometimes parts would not stick together."*

Materials and Resource Constraints. The pre-service teachers voiced practical concerns related to the limited availability of filament materials. These were in terms of filament quantity and color variety. As indicated in their feedback,

P5: *"Sometimes we ran out of filament rolls."*

P15: *"There were only limited filament colors…I cannot use the color that I wanted."*

Lack of Instructional Support. Some pre-service teachers reflected on their reliance on feedback from their instructor to assess, refine, and improve their models. However, their responses also indicate varying levels of support from the instructor and a notable shift toward peer-based feedback systems. They recounted,

P18: *"There was not enough constructive feedback from our instructor…Though I understand, since there were many of us in the group."*

P20: *"Our instructor commented on the models I have drawn. But I mostly asked for comments from my classmates."*

Discussion

Scientific Skills Developed by the Pre-service Teachers After Using the 3D Pens

By using 3D pens, the pre-service teachers gained familiarity and the ability to plan and implement their use in science instruction. Generally, they agreed on their acquired science skills, suggesting that integrating the pens can effectively enhance competencies aligned with 21st-century learning and basic scientific processes. Among the skills assessed, creativity emerged as the most highly rated. This suggests that 3D pens were a highly effective tool for fostering creative thinking among participants, aligning with Chun (2021). The enhanced creative skills may relate to the visualization described by Mnguni (2014) and the spatial thinking abilities outlined by Ishikawa and Newcombe (2021) and Rohmah et al. (2021). The pre-service teachers' responses illustrate how the pens catalyzed creative expression. This points to the role of the tool in transforming internal ideas into concrete models. This underscores how creativity fostered by a 3D pen extended beyond model-making into pedagogical innovation.

Similarly, their strong agreement for technological skills indicates that the 3D pens provided authentic experiences that enhanced technological confidence. This was particularly true among pre-service teachers with little or no prior exposure to 3D printing technologies. The growth in technological skills was notable, given their initially low

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familiarity, aligning with Koehler and Mishra's (2009) TPACK framework for teacher preparation. Responses explicitly noted that they had never encountered or operated a 3D pen before. Their initial lack of experience underscores the pens' inaccessibility to tap their potential for skill acquisition through structured learning opportunities. Their acquisition of technological skills after using the pens demonstrates the transformative impact of even short-term exposure to hands-on technology.

Meanwhile, the pre-service teachers also acknowledged gains in critical thinking, communication, and collaboration. Their reflective feedback showed that the 3D pen is a robust medium for engaging in cognitively demanding tasks. Creating 3D printed science models requires more than basic drawing ability. It necessitates cognitive awareness, structured planning, and iterative decision-making. Their planning suggests that using the pens required them to anticipate the relationship between individual components and their final form. Their indication of minimizing material filament waste while achieving design accuracy demonstrates how the pen creates an authentic space for evaluative reasoning and forward thinking. This could be related to the enhanced problem-solving skills of pre-service teachers. It may also indicate the development of acquired spatial thinking abilities, as noted by Chen et al. (2021).

Regarding communication and collaboration skills, the pre-service teachers' responses indicate that using the 3D pens necessitated interpersonal interaction, shared decision-making, and collaborative problem-solving, indicating their awareness of the pens' role in fostering interpersonal skill development. This may also indicate variability in instructional design or group dynamics. The communication and collaborative modeling process mirrors the real-world nature of scientific work. Thus, these results may indicate the need for more structured collaborative tasks, feedback opportunities, or team-based model construction to fully harness the communicative and cooperative potential of 3D pen use.

Concerning basic science process skills, participants agreed that using 3D pens helped develop measurement, classification, and inference skills. Estimating measurement emerges as a developed skill and a notable issue when using the pens. This was more likely affected by the freeform and manual nature of the pens, which often led them to rely more on visual estimation. Measurement skills were likely reinforced as they had to consider scale and dimensions in designing and constructing models. This finding resonates with using informal measurement strategies in hands-on learning environments. It also captures the indications of these skills as divulged by the CHED (2017) and DepEd (2016, 2023).

Classification and inference, on the other hand, may have been exercised as participants analyzed structures and organized information to accurately represent scientific phenomena. As the pre-service teachers' feedback indicates, while these cognitive processes were not the most prominently developed, they were nonetheless utilized implicitly during the planning and construction of models. This suggests that the pens can contribute to foundational science skills, particularly when design tasks require structured planning and imaginative foresight. The pre-service teachers anticipated the outcome of a model before its physical realization. The classification process involved breaking complex objects into functional or representational parts, where sorting and organizing model components were critical. The development of 21st-century and basic science process skills suggests that integrating 3D pens contributes to a multifaceted skill set among pre-service teachers. This agrees with users' developed skills that emerged from using the pens, as observed by Bernard and Mendez (2020), Dean et al. (2016), and Imeri et al. (2017). This supports the value of incorporating the pens into science education coursework to nurture cognitive and technical skills among future educators.

From a pedagogical integration standpoint, the results strongly align with Koehler and Mishra's (2009) TPACK framework, wherein 3D pen operation (TK), accurate science representation (CK), and embedding tasks in science learning (PK) intersect meaningfully. This reinforces that developing 21st-century and basic science process skills requires simultaneous cultivation of content mastery and technological proficiency. By embedding 3D pen-based modeling into teacher preparation programs, educators can create authentic, hands-on experiences that prepare future educators to facilitate visualization and integrate technology with curriculum goals. The implications for the participating pre-service teachers are clear: structured 3D pen activities can serve as both a cognitive and pedagogical training ground, enabling them to design learning experiences that mirror the demands of modern, skills-based science instruction.

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Perceptions of the Pre-service Teachers Regarding the Potential Use of 3D Pens as Educational Materials for Primary Biology and Chemistry Education

The pre-service teachers expressed strong overall perceptions of the educational potential of 3D pens, underscoring their emerging value as transformative tools in modern science classrooms. The most notable finding is the perfect mean score for instant 3D object creation, indicating unanimous agreement on one of the pen's key strengths: its ability to rapidly transform abstract concepts into tangible forms. This capability underscores the unique position of the pens in facilitating immediate, hands-on visualization, which is particularly beneficial in constructing scientific models. The unanimous perception of the pens' instant 3D printed object creation points to their unique role in enabling rapid, tangible model construction, which is a process that supports both conceptual understanding and science process skill development. These findings align with those of Chun (2021), João et al. (2020), and Kolitsky (2014), positioning 3D pens as a bridge between abstract scientific concepts and tangible learning experiences. This rapid translation from mental image to physical model reflects the dual visualization and drawing process described by Mnguni (2014) and Chen et al. (2021). The pre-service teachers' responses reflect a growing pedagogical emphasis on immediacy, embodiment, and student-centered learning in teacher education. They found the process of drawing and simultaneously producing 3D printed models satisfying, novel, and empowering. Unlike other modeling tools that require planning, processing time, or software proficiency, the pen collapses the gap between idea generation and instant model realization.

The pre-service teachers also strongly agreed that 3D pens are stimulating, motivating, and engaging. This reflects the pens' ability to create a high-interest learning environment that fosters both emotional engagement and cognitive investment, which are critical in sustaining attention and deepening learning. The pen's interactive nature likely appeals to these responses by offering hands-on experiences contributing to their meaningful learning experiences. The participants' responses consistently highlight how the novel nature of 3D pen activities increased their intrinsic motivation, sustained their attention, and reduced stress. The stress-reducing effect of the pen may be particularly valuable in teacher education programs, where pre-service teachers often face anxiety related to mastering new pedagogical tools for STEM or STEAM learning. The pens may offer low-risk, high-engagement experiences, serving as a confidence-building tool. The pre-service teachers' perceived motivation and engagement align with the enthusiasm noted by Imeri et al. (2017) and the enjoyment observed by Bernard and Mendez (2020).

Pre-service teachers strongly agreed that the pens have the potential to support science learning and enable exploration and validation of scientific ideas. This positions 3D pens within the broader movement toward inquiry-based and constructivist science education. These perceptions suggest that the pens were seen not merely as novelty tools but as functional aids in scientific inquiry. Based on responses, the ability of the pens to render immediate, manipulable, and personalized representations of abstract scientific ideas plays a central role in this perception of usefulness. Another result is the strong agreement on the perceived interdisciplinary learning opportunities using the 3D pens. There was an acknowledgement of the opportunity for cross-curricular connections of science with other areas. For instance, this aligns with global educational priorities encouraging STEM or STEAM education, where disciplines are integrated to solve complex, real-world problems. The pen's affordances in design and art naturally bridge science and engineering with creativity and innovation. As revealed in the responses of pre-service teachers, the interdisciplinary nature of 3D pens makes them particularly well-suited for the integrated primary science curriculum.

From Koehler and Mishra's (2009) TPACK, the perception results suggest that pre-service teachers recognize the technological affordances of 3D pens (TK) and their alignment with inquiry-based, student-centered pedagogy (PK). High ratings for supporting science learning and enabling the exploration and validation of scientific ideas indicate an emerging TPACK that demonstrates the capacity to blend technological, pedagogical, and content expertise in designing practical lessons. The interdisciplinary learning score further reflects PCK and TCK, where technology directly supports the representation of complex biology and chemistry concepts. High ratings for fostering interdisciplinary learning and stimulating engagement align with spatial thinking. As conveyed by Takahashi and Kim (2019), the pens enabled iterative refinement, experimentation, and testing of ideas, which are practices that parallel the exploratory and constructive nature of scientific inquiry.

The pre-service teachers agreed on the accessibility, portability, and ease of use of the pens. They have consistently expressed that the pens were intuitive, quick to learn, and required minimal infrastructure. These characteristics highlight the simplicity of the pens, as noted by Cardoso et al. (2020), de Oliveira et al. (2020), João et al. (2020), and Takahashi and Kim (2019). This makes the pens highly practical for instructional use and student-centered learning in science education. The pens' straightforward button controls and familiar pen-like form make

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them ideal for early integration into classroom activities, including for users with limited exposure to digital tools. The cost-effectiveness of acquiring and maintaining the pens, compared to larger and more complex fabrication equipment, positions them as economically feasible tools for both pre-service teacher training and future classroom use. The ability to purchase these tools from online retailers adds to their widespread accessibility, furthering access to technology-enhanced learning.

Additionally, the perception that 3D pens have an enduring impact on learning is slightly lower than other indicators. This suggests that while the pens may serve as practical tools for immediate engagement and understanding. Their long-term educational value may depend on how well they are integrated into sustained instructional practices. The pre-service teachers' overall perceptions signify that they found the 3D pen to be a valuable, relevant, and effective tool for supporting various cognitive and experiential learning dimensions. This aligns with the growing advocacy for incorporating emerging technologies into teacher and science education.

Problems Experienced by the Pre-service Teachers When Using the 3D Pens

While 3D pens hold strong potential for enhancing science education, their use also poses notable technical and pedagogical challenges, offering valuable insights into the practical limitations and support needed for their effective classroom integration. The most commonly determined technical issue is the requirement for the pens to be continuously plugged into a power supply. Though it is the manufactured design of the pens, this highlights the limitations posed by the pen's mobility and energy requirements, especially in learning environments where access to electrical outlets is limited or classroom configurations must be flexible. These issues affect the pen's portability, as highlighted by de Oliveira et al. (2020), and accessibility, as noted by Takahashi and Kim (2019). The pen's reliance on electricity may inhibit widespread or spontaneous use unless alternative portable or battery-powered options become available. This immobility may hinder collaborative group work, restrict user movement, and increase the risk of accidents due to trailing cords or shared power connections. For 3D pens to be fully integrated into modern classrooms, it is suggested that there is a need for either improved spatial and infrastructure demands, such as availability of safe power outlets and extension cords, or a transition to battery-powered or wireless pen alternatives that support flexible usage.

The frequent need to refill filaments poses logistical and financial challenges, highlighting material and resource constraints, particularly in filament supply and color variety. Imeri et al. (2017) indicated that 3D pens can use a significant amount of filaments. Filaments are consumables and often depleted quickly during hands-on activities, especially when users are still developing proficiency and may waste material. Since filament is essential for the pen's function, its depletion mid-task disrupts model-making and increases the cost burden on users. The lack of color availability may also affect the model design. While seemingly minor, this issue can be pedagogically significant, particularly when the pens are used to model concepts in science that rely on visual differentiation. This problem points to the importance of sustainable resource planning in integrating pens into educational technology. Limited filament supply further compounds this issue, suggesting that resource allocation must be addressed if 3D pens are used regularly in teaching practice. This highlights the need for resource planning, where considering cost-effective and recyclable options is recommended for sustainability.

The pre-service teachers struggled with precise models and creating large-scale models, noting limitations in producing straight lines and refined surfaces. These concerns underscore the 3D pen's design limitations of manual extrusion. The difficulty in rendering straight edges or smooth textures makes the pen more suitable for freeform and smaller-scale educational models, but less ideal for making precise or technical design concepts. They determined difficulties in achieving fine, precise, and detailed models, reflecting a mismatch between the pen's capabilities and the accuracy expectations in science modeling tasks, echoing Bernard and Mendez (2020). The manual operation of pens requires fine motor control and artistic dexterity, which can pose barriers for novice users.

The difficulty in constructing large-scale models is also a significant issue. Due to the pens' manual operation and limitations in filament output volume, creating large or structurally stable models becomes a challenging task. This may also be attributed to the time-intensive nature of manually constructing complex structures, the ergonomic limitations of the pens, or the inconsistent quality of the output. These limitations could hinder the pen's application to more ambitious or complex educational projects and may require creative task designs. This restricts the use of the pens for more advanced or comprehensive projects, suggesting a need to align learning tasks with the scale and scope that can be managed through the pen, perhaps by focusing on modular or smaller components of scientific models.

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Considering the nature of the PLA and ABS filaments, the unpleasant odor of heated filaments introduces a sensory and potential health concern in confined or poorly ventilated spaces. This smell is an inherent property of the filaments when melted, often resembling the scent of burning plastic, as noted by Bernard and Mendez (2020). This problem could discourage extended or repeated use, thus limiting the instructional value of the pen. Thankfully, the model-making activity was set in a well-ventilated area, and the face mask provided to the participants contributed to mitigating smell irritations. The need to wear a face mask reflects an adaptive safety measure among users to lessen discomfort. Suppose 3D pens are to be adopted in formal instructional contexts, safety protocols such as wearing face masks, ensuring well-ventilated workspaces, and setting limited exposure durations must be established to prevent potential health risks and discomfort. The preference for using non-toxic, less odorous filament alternatives, such as biodegradable PLA filaments, over ABS is also recommended.

The occurrence of filament stringing, as reported by some pre-service teachers, reflects a common technical issue that is often encountered during 3D pen usage. Stringing occurs when molten filament continues to ooze from the nozzle during pauses or transitions, forming fine, thread-like strands that resemble spiderwebs. This common problem is consistent with the stringing observed by Takahashi and Kim (2019). This issue is a practical concern for model aesthetics, affecting model clarity, structural precision, and user experience.

While the risk of skin burns from heated 3D pen nozzles is reported by half of the pre-service teachers, making it less frequently encountered than other technical issues, it remains a notable safety consideration. This concern was similarly raised by Bernard and Mendez (2020) and Imeri et al. (2017). The relatively moderate frequency suggests that while burn incidents or concerns were not pervasive, the potential for injury is real, particularly for novice users unfamiliar with handling heat-emitting tools. The design of most pens includes metallic nozzles that reach high temperatures. Contact with these heated tips can result in minor burns or discomfort, which, while not commonly reported in this study, represents a latent hazard, mainly when used with limited supervision. That only half of the participants noted this as a concern may reflect the adequacy of safety precautions, such as pre-use orientations, instructor supervision, user caution, and the mandatory use of cotton gloves. It may also indicate a growing familiarity and confidence among pre-service teachers in safely operating the pens. However, the relative infrequency of this issue should not lead to complacency.

A minority of pre-service teachers experienced the functional operation issues of the pens. This may be due to the elimination and substitution of pens, which caused numerous technical issues during the pilot testing. It may also be due to the frequent maintenance of the pens after every use. Other technical issues, such as filament clogging, nozzle overheating, and design stability, are reported less frequently but still pose barriers for less experienced users. Interestingly, filament stickiness, nozzle blockage, and slow hardening time are among the least reported issues, indicating that some operational aspects may be less problematic than expected, especially when basic handling procedures are followed. This is in contrast with the identified clogging issues by Bernard and Mendez (2020) and Imeri et al. (2017). With its smooth surface texture, the glossy photo paper helped prevent the filament from sticking to it. This suggests that while these are known issues associated with using 3D pens, they can be mitigated through proper training, high-quality materials, and regular maintenance.

Among pedagogical issues, the most prominent is the lack of skills and practice using 3D pens. This indicates that familiarity with the pen does not come intuitively and requires structured instructional guidance and support. This issue does not reflect the user's immediate use of the pens, even without prior experience, as indicated by Bernard and Mendez (2020) and Imeri et al. (2017). While 3D pens may appear simple to operate, effective educational use demands the ability to conceptualize and design instructional models that align with scientific content. This underscores the necessity of explicit, scaffolded training for pre-service teachers, not just in the technical handling of the tool, but in its pedagogical application. This includes aligning 3D modeling with science learning outcomes and curriculum standards. Closely related is the issue of mastering techniques for precision, which likely overlaps with the technical difficulty of producing accurate designs. Guided practice and iterative feedback are crucial for acquiring and mastering skills.

Another major issue is time limitation, reflecting the challenge of balancing innovative learning activities with the tightly structured schedules typical of teacher education programs. The process of conceptualizing, designing, and producing 3D printed models is inherently time-intensive, suggesting that unless ample time is allocated for exploration and project completion, the educational benefits may be undermined. This highlights the need for curricular integration that provides extended, flexible opportunities for technology-enhanced, project-based learning. While active, constructivist learning activities offer rich pedagogical value, they also require more classroom time than traditional instruction. This raises concerns about the feasibility of integrating 3D pen-based

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projects within fixed curriculum schedules, especially in teacher education, where multiple competencies must be addressed within a limited timeframe.

The pre-service teachers reported issues with achieving precision, structural integrity, and high-quality design output using the 3D pens. They expressed difficulty in producing models that matched their intended design, often citing frustration over inaccurate forms, weak bonding between components, and the fragility of final models. These quality issues coincide with those enumerated by Dean et al. (2016), Imeri et al. (2017), and Takahashi and Kim (2019). Since models are constructed by layering extruded filament line by line, without the uniform flow regulation, the bonds between layers and parts are often weak or inconsistent. The absence of support structures or adhesive mechanisms makes it difficult for users to ensure strong connections between components, especially in multi-part models.

Conversely, very few participants expressed concerns about the pens being engaging or the conducive working space. This suggests that environmental and motivational barriers are less impactful than technical or skill-related ones. It may imply that these conditions were generally favorable among the pre-service teachers. In this case, 3D pens retained their engagement potential, even if practical and instructional concerns limited their effectiveness. Although not ranked among the highest issues, the pre-service teachers hint at the important role of instructional support. A moderate proportion of participants reported insufficient instructor feedback and a lack of structured activities. Feedback serves as a central mechanism through which students can reflect on their work, identify and adjust misconceptions, and refine their outputs. The lack of feedback indicates a need for instructors not only to be competent in using 3D pens but also to be intentional in guiding their integration into learning activities, offering targeted feedback, and helping pre-service teachers reflect on both the product and the process. Faculty professional development and modeling of best practices in using the pens can help.

Conclusion and Implications

3D pens have demonstrated their utility as innovative tools to enhance primary teacher education by bridging science content knowledge, creativity, and hands-on engagement. This study examined the experiences of BEEd pre-service teachers using 3D pens in primary biology and chemistry education. It aimed to evaluate their development of science skills. It examined their overall perceptions of the pens and the problems they encountered when using them. Using the pens among the primary pre-service teachers has revealed a dynamic interplay of skill development, perception, pedagogical potential, and issues. They strongly agreed that 3D pens enhanced their creative and technological skills. It revealed that pre-service teachers have a favorable perception of 3D pens as educational tools. Despite these promising skills development and positive perceptions, the study disclosed several technical and pedagogical problems encountered by the pre-service teachers. Conclusively, the study substantiates that 3D pens offer a novel and engaging educational tool that can significantly support teacher education training and primary science education.

With the results, the study implies that integrating hands-on technologies, such as 3D pens, can enrich primary biology and chemistry instruction by making abstract and conceptual topics more tangible and engaging. The use of the pens promotes active learning, indicating that teacher preparation programs can leverage them to support the holistic development of teaching competencies aligned with modern educational standards. Doing so may equip future educators with firsthand experience integrating creative, student-centered tools into their instructional practice, particularly in teaching abstract scientific concepts.

Limitations and Recommendations

One limitation of the study is the small sample size. The study was conducted with a limited number of primary pre-service teachers within a single institution and program, which may constrain the generalizability of the findings. While the study provides valuable insights into the perceived benefits and problems of using 3D pens in science education, the results may not represent all primary pre-service teachers across diverse educational contexts. Another limitation is the pre-service teachers' exposure duration to using the pens. They were only given a limited time to familiarize themselves, practice, and use the pens to create models. This short-term exposure may not have allowed them to fully develop mastery or explore the pens' full range of functionalities, potentially affecting the depth of skills acquired and perceptions formed. A further limitation of the study relates to the specific model or brand of 3D pens used during the intervention. Since only one type of pen was provided to the participants, their experiences, problems, and perceptions were shaped by the characteristics of that particular device. Therefore,

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the results may not be fully generalizable to other pen models, especially those with more advanced features or differing technical specifications. Lastly, another limitation concerns the type of filaments used during the modeling activities. PLA and ABS filaments with specific brands were used, each with distinct characteristics that may have influenced their experiences. As such, the findings related to ease of use, model quality, and safety cannot be generalized to all filament brands and materials.

For related research, future studies may include a larger, more diverse sample across multiple institutions to improve the generalizability of the results. Comparative studies between 3D pens and other modeling or visualization tools are recommended to determine the relative strengths and limitations of 3D printing technologies. Further research may assess the long-term effects of using 3D pens on pre-service teaching performance, instructional innovation, and student learning outcomes in actual classroom settings during teaching internships.

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Authors' Contributions

All authors contributed to the review, editing, literature review writing, planning, and implementing the research. All authors contributed to the data collection and analysis. All authors have read and approved the final version of the article.

Conflict of Interest

The authors declare no conflicts of interest in this paper.

Ethics Declaration

The Saint Louis University (SLU) - Research Ethics Committee (REC) reviewed this study for ethical clearance. The study was then approved with protocol number SLU-REC 2025-140.

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